Education of Wireless and ATM Networking Concepts Using Hands-On Laboratory Experience

Krishna M. Sivalingam
School of Elect. Engg. & Computer Science
Washington State University
Pullman, WA 99164-2752
Email: *krishna@eecs.wsu.edu*

V. Rajaravivarma
Dept. of Electronics & Computer Technology
North Carolina A&T University
Greensboro, NC 27411
Email: *veeramu@ncat.edu*

Abstract –

Traditional computer networking courses primarily tend to provide students with hands-on software development and network performance experience with TCP/IP and Ethernet networks. Our objectives are to enhance the curriculum of networking courses and the expertise of students by introducing next-generation networks such as wireless and ATM networks. To facilitate this, we have established a wireless ATM network instructional facility (NIF) at Washington State University (WSU). Projects based on ATM networks and wireless networks have been introduced in a course on undergraduate computer networks taught at WSU during Spring 1998. This paper describes the laboratory setup, the projects and assignments, and the feedback obtained from the students.

1 Introduction

The purpose of this paper is to describe the introduction of advanced networking concepts including wireless and ATM networks in undergraduate and graduate courses. Two separate wireless and ATM network laboratories are being established at Washington State University (WSU) and project partner, North Carolina A&T University using funding from the National Science Foundation's ILI grant program.

In particular, the paper describes the experience from teaching a senior undergraduate networking course taught during Spring 1998 at WSU. The undergraduate and graduate students were able to obtain hands-on learning experience with wireless and ATM networks and conduct performance comparison to traditional TCP/IP and Ethernet networks. The paper describes the course information, projects, student feedback, and the experiences gained by the instructor.

[1]This work was supported by the National Science Foundation under Grant DUE-9751198 and through matching funds from Washington State University and North Carolina A&T State University.

2 Motivation

The motivation for establishing these laboratories and the subsequent education is described in this section.

In a typical undergraduate course in networking, the fundamentals of networking and introduction to programming in TCP/IP are covered [11, 5]. Topics including Open Standards Interconnection (OSI) hierarchical protocol architectures and application programming using BSD Sockets [4] or WinSock interface are usually taught.

The local area network used in typical networking courses is Ethernet [11]. Ethernet is available in two modes: Switched Ethernet and Shared Ethernet. In Shared Ethernet, the medium is shared by all the users connected to the medium. In Switched Ethernet, each user is provided a dedicated link to the Ethernet Switch. Ethernet is available at speeds of 10 Megabits-per-second (Mbps), 100 Mbps and 1000 Mbps in each of the two modes. Since the cheapest and hence most common network is currently Shared Ethernet at 10 Mbps, it is used in most networking courses.

There are newer technologies on the horizon such as wireless and ATM networks that are beginning to be more widely deployed. There is a need to teach advanced networking concepts based on these networks to undergraduate students in particular. This forms the motivation of the work reported in this paper.

Wireless/mobile network technology provides tether-less access to mobile users and usually operates at 1-2 Mbps. Higher speed wireless networks that operate at 10 Mbps are also becoming available. Wireless networks operate in a shared mode with a number of wireless users sharing the medium. Wireless communication has been through two generations of development [9]. The first generation of wireless networks supported typically voice only communication. The second generation of wireless networks support both voice and data using networks such as CDPD, ARDIS, WaveLAN, and so on [9]. The third generation promises support for multimedia with quality-of-service provided, and easy web access.

Wireless communications courses typically tend to focus more on the wireless channel and communication characteristics. There is a growing body of research that is addressing the impact of wireless channel on higher-level protocols. Students should gain experience with developing applications for wireless networks to better understand them from a networking protocol perspective.

The goal of introducing wireless networks is to teach students the basics of wireless networking, to emphasize the network characteristics such as low bandwidth, higher bit error rates and varying network conditions that impact protocol design, and to provide hands-on project based experience with a wireless LAN.

Asynchronous Transfer Mode (ATM) network technology that operates at speeds of 155 Mbps and 622 Mbps [10, 7]. ATM networks operate in the switched mode, with each user having a dedicated link to the switch. Currently, 155 Mbps networks are more common in the LAN network since they are cheaper. ATM is potentially both a local area network (LAN) technology and a wide area network (WAN) technology.

ATM networking was designed to deliver Broadband Integrated Services Networks (B-ISDN). Its main goals are to support multimedia, deliver quality-of-service, and offer faster cell-based switching. The current status of ATM network deployment indicates that ATM is a leading choice for back-bone networks. However, ATM does not appear poised to capture the desktop and local area network market where Ethernet, Switched Ethernet, and Gigabit Ethernet may ultimately succeed. But, exposure to local area ATM networks will help them grasp the fundamentals of backbone wide-area ATM network operation.

An introduction to the basics of ATM is now found in recent networking textbooks such as [11]. What is lacking is providing the students with actual hands-on experience in native ATM Application Programming Interface (API), IP over ATM, and in learning the differences between ATM and TCP/IP based networks. This motivation has led to the establishment of a teaching laboratory that contains a set of computers interconnected through an ATM switch.

The main characteristics that differentiate ATM from TCP/IP networks is that the network and transport layer protocols [11, 7] are fundamentally different. For example, ATM uses virtual-circuit based routing while TCP/IP uses datagram based networking. TCP/IP provides a reliable byte stream service, while ATM does not have an equivalent reliable transport layer protocol. As a LAN technology, ATM provides switched mode LAN connection compared to the traditional shared mode Ethernet LAN connection. The goal of introducing ATM networks is to teach the basics of ATM networks, to emphasize the characteristics of ATM networks that influence protocol design, and to provide class project based experience.

One of the key teaching goals is to provide project-based hands-on experience in software design and implementation for ATM and wireless networks. The students will be expected to work with application and protocol development. The knowledge gained from application development will enable them to better understand the underlying networks and protocols. It will also enable them to better understand existing networks based on Ethernet and TCP/IP, and appreciate the design differences between the different networks.

3 Laboratory Setup

The network instructional facility (NIF) lab consists of a set of five Intel Pentium-based computers. a Fore ATM switch [1], and a Lucent WavePOINT wireless bridge [8]. The ATM switch has 12 155 Mbps ports. Each computer has a 10 Mbps Ethernet interface, a 2 Mbps Lucent WaveLAN interface, and a 155 Mbps Multi-Mode Fiber (MMF) ATM interface. The computers are connected to the department backbone through the Ethernet network.

One of the machines is set up as a Windows NT server and another as a Linux server. The other three machines are set up to be Linux/NT dual-boot clients. A substantial effort was required to find the right Linux version that will support Linux-ATM, Linux-WaveLAN and Ethernet drivers.

The short-term lab enhancement under pursuit is the addition of 10/100 Mbps Switched Ethernet, 1 Gbps Gigabit Ethernet, and 10 Mbps wireless networks.

At NC A&T University, a new building for the School of Technology will be completed in December 1998. The advanced network laboratory will be located in this facility. At present, the required equipment have been obtained but not yet installed, pending completion of the building.

4 Courses Offered

The courses currently offered at WSU that will make use of the lab include:

CptS/EE 455 – Computer Networks: This is an undergraduate course in networking which will introduce students to the fundamental concepts of computer networks. The current textbook followed for the course is Tanenbaum's "Computer Networks", Third Edition. CptS/EE 455 was taught using the NIF laboratory in Spring 1998 and had an enrollment of 27 students.

CptS/EE 555 – Computer Communication Networks: This is a graduate course which is also available to advanced undergraduates. The students are exposed to analytic techniques to understand the design decisions and performance of computer networks. A term project, done in teams, is expected as part of the course.

CptS/EE 555 is being taught using the laboratory in Fall 1998 and has an enrollment of 32 students. This course is being offered over the Washington State Higher Education Technology Services (WHETS), a distance learning center taught to three WSU campuses – Pullman, Spokane, and TriCities. The textbook followed for the course is Berstekas and Gallager's "Data Networks" book.

CptS 557 – Advanced Computer Networks: This is an advanced graduate course in computer networks. The focus of this course is teach the latest advances in computer networks, including topics such as light-weight transport protocols, IP over ATM and WDM networks, wireless multicasting algorithms. This course will also include a term project. The course will be taught using the NIF lab during Spring 1999.

5 Experience with CptS/EE 455

This section describes the course and assignment details of CptS/EE 455 course, taught to 27 students during Spring 1998. All course materials are available on-line at [6].

5.1 Course syllabus

The course was taught using Tanenbaum's "Computer Networks", Third Edition, in roughly the following order:

1. Introduction to Computer Networks covered from Chapter 1. In addition to the OSI and TCP/IP models, a brief introduction to ATM and wireless networks was provided;

2. Summary of the physical layer media such as copper, fiber, satellite, and wireless media was covered. In addition, access technology such as modems, satellite access, xDSL access was also introduced;

3. Transport layer protocol issues, the different Automatic Repeat Request (ARQ) mechanisms, a description of the TCP/IP standard, and the BSD socket API were taught.

   Transport layer topics related to the ATM layer , and the key differences between transport layer in ATM and TCP/IP networks were taught. Mobile TCP modifications such as snoop TCP and indirect TCP were covered.

4. Data link layer topics such as framing and error correction were taught

5. Medium Access Control (MAC) protocols including Aloha, CSMA/CD, Ethernet, and wireless LAN MAC protocols including CSMA/CA and IEEE 802.11 standard were taught.

6. Routing algorithms such as Bellman-Ford and Djisktra's algorithm, the IP network layer, and the ATM network layer were covered. The differences between the IP network services and ATM network services in terms of quality-of-service were covered.

5.2 Projects and Assignments

The course required the students to work on the following three projects, in order:

FTP Client and Server: The objective of this project was to implement an FTP client, and an FTP server using the BSD Socket Interface. The teaching objectives were: (i) to familiarize students with writing a network application using TCP/IP programming, (ii) read, understand, and implement Internet Request for Comments (RFC) standards, (iii) teach the client-server model, and (iv) understand the synchronization difficulties involved in client-server communication.

There are two major components to the project: (i) the FTP server, and (ii) the FTP client. The Internet FTP protocol standard definition provided in Internet RFC 959 was used as the basis for the implementation. The implementation required was *similar* to the minimal implementation outlined in Section 5.1 of the RFC. The server and client were expected to support NLST, CWD, RETR, PWD, and QUIT commands. The operating system platform was Unix (Linux or HP-UX).

The students were provided with some of the basic files required to set up sockets for client and server processes. This material was derived from [4]. The students were also provided pointers to the OS system calls (such as *getpwd(), chdir(), readdir()*) required for the FTP server.

This project thus accomplished student familiarity with the basics of TCP/IP programming and the intrinsics of application protocol implementation.

Stop-and-Wait ARQ Protocol: The objective of this project was to implement the Stop-and-Wait ARQ transport protocol and then measure the round-trip delays, estimate timeouts, and obtain throughput performance results. The protocol chosen was the *Unidirectional Protocol with Positive Acknowledgments and Retransmission*, similar to the Protocol 3 described in [11]. The teaching objectives were: (i) practical understanding of the complexities of implementing a simple data-link protocol, (ii) performance analysis varying different system parameters, and (iii) comparison of the performance of Ethernet, wireless, and ATM networks.

The project required two separate programs, running at the same time, on two different hosts: a *sender* program that generates and transmits packets; and a *receiver*, that accepts the packets, and transmits the acknowledgments to the sender. Communication between the sender and receiver was through UDP sockets. Thus, the receiver was set up as a UDP server, and the sender was set up as a UDP client. Therefore, the students were required to implement a simple reliable transport protocol on top of unreliable UDP.

For every packet acknowledged, the round-trip time (RTT) was calculated that was used to update RTT and Deviation, used to calculate the timeout values. The update formulae are as outlined in the TCP standard and described in [11]. On termination, the sender program was expected to output: (i) Final RTT Estimate, (ii) Throughput, in bits-per-second, and (iii) Transmission Efficiency (i.e. number of transmissions per packet).

This project was tested using the Wireless Interface and the Ethernet interface. The system parameter varied was the packet length ranging from 128 bytes to 32 Kbytes. The students then plotted a graph showing the variation of the measured parameters to packet length, comparing Ethernet and wireless network performance.

This project thus provided students with insight into implementing a simple ARQ protocol and performance analysis of the protocol. It also enabled them to compare the performance on a wired and wireless network.

The students were also asked to analyze, for extra credit, the performance of the protocol on ATM networks. The TCP/IP program could be modified to run on top of the ATM interface, due to the availability of IP over ATM on Linux.

MAC Layer: Ethernet vs. ATM The objective of this project was to compare the performance of two different type of local area networks (LAN): shared 10 Mbps Ethernet, and switched 155 Mbps Asynchronous Transfer Mode (ATM) networks. The objectives were to: (i) introduce students to network programming using the ATM Application Programming Interface (API), (ii) show performance differences due to transmission speed in Ethernet and ATM networks, and (iii) to depict the impact of heavy network traffic on switched versus shared mode networks.

The performance comparison was be achieved using a small skeleton application, that represents a file server/client operation. This was used to generate traffic that resembles that of a network file system.

The project required two separate programs, running at the same time, on two different hosts: a *FileClient* program that generates and transmits request packets; and a *FileServer*, that accepts the packets, and transmits the responses to the FileClient. Communication between the FileClient and FileServer is through UDP sockets for Ethernet, and AAL5 for ATM.

For the Ethernet network, TCP/IP is the transport/network protocol layer. Therefore, we used traditional BSD sockets to develop the programs for Ethernet.

For the ATM network, we used the native ATM layer and AAL5 layer interface. The addressing syntax is different from that of IP, and a separate handout was provided explaining the ATM-socket interface [6]. The Linux-ATM implementation was obtained from [3]. Getting the ATM API to work and setting up the different Virtual Circuits was a time-consuming experience. The students were made to realize the fact that Virtual Circuits are required for an ATM network and also shown how they were set up.

The performance parameters measured were throughput and round-trip delay. The system parameters varied were the traffic generation rate and packet length. In general, large packet length and high traffic generation rate resulted in Ethernet collapsing due to collisions. On the other hand, ATM was able to sustain the higher traffic rates without collapse.

This project thus accomplished the task of providing insights into the key differences between shared Ethernet and switched ATM networks. Students were also taught how the Virtual Circuit addressing of ATM works in comparison to IP's addressing. Due to the enormous amount of time it took to set up the ATM network, we could not accomplish more with regard the ATM networking concepts. In future course offerings, we plan to enhance this project.

Netperf performance: Netperf [2] is a benchmarking tool used to measure TCP and UDP level performance for a given system. This is public domain software and obtained from [2]. In order to provide students exposure to such tools, a homework assignment was given to the students based on netperf. The students ran netperf on wireless interface and Ethernet interface and compared the throughput obtained for varying message sizes. This was a relatively simple and short assignment when compared to the previous ones. However, the goal was to teach students how different interfaces coexist in a single system, how a different IP address is used for each hardware address, and how the cards can be accessed.

5.3 Feedback

This section describes the feedback obtained from the students. Three types of feedback were obtained from the students: (i) A Mid-term feedback based on a questionnaire provided by the instructor, (ii) Project Feedback for every project, and (iii) Term feedback based on forms provided by the university.

Here, we will highlight some of the feedback received along with the submission of every project. The students were asked to comment on their experiences, suggestions to improve the project for better learning, etc. Some students were so excited about the projects that they proposed their own ideas that could be used a new course project. Listed below are some verbatim comments from the students:

Project 1: FTP client and server

... The experience (for FTP project) has been very challenging and interesting at the same time, mainly the string manipulations and trying to solve deadlocks between the server and the client...

... I felt that this project was very informative in the workings of TCP/IP applications. ...

... My experience with this project was largely a positive one. ... The difficulty was not in implementing the functions, but in "synching" up the client and server with regard to their communication via acknowledgments. ...

Other comments reflected the same feeling that the project was tough and challenging, but finally getting FTP to work between two machines was worth the effort. There was also a number of constructive suggestions for improvement, such as providing a set of smaller lead-in assignments.

Project 2: Stop and Wait Transport Protocol

... I enjoyed the project. ... Although it would have been nice if the error ratio would have been greater. I was never sure if the timeout worked properly or not. It appeared that the wavelan card was almost as reliable as the ethernet. ...

... It was a good project especially because of its practical implications and its instruction about stop-and-wait and UDP ... I was a little confused about what method you wanted us to use to calculate the RTT ...

... I enjoyed working on this project immensely. ... I gained a great deal more this time, since I could concentrate more on knowledge and correctness. I think this was an excellent project and would be worthwhile for future cs455 classes.

... This project was entertaining as well as challenging. I was not aware of how many packets can be lost over a network. And I had no idea how hard it was to detect which packet was lost ...

... I would have liked to run the test cases with ATM as well, and make my report by comparing all 3 networks ...

Overall, the students were really satisfied with learning the complexity of implementing a simple ARQ protocol, and were willing to implement sliding window ARQ protocols to learn more.

Project 3: MAC Protocol

... I think this project was very useful for the ATM part. But, in the ATM I had to build almost everything from scratch ... Trying to test wasn't easy. The testing results varies depending on the day (of course, because of the traffic). ...

... I really liked it because at least I got to see how a socket is allocated with ATM AAL5 ... I like to take this opportunity to say that I really liked the practical side of the class ...

... This exercise was beneficial to me. It allowed me a chance to program with the concepts of ATM rather than just learning about them in class. It drove the idea of network efficiency further into my skull.

... I believe that observing the performance on the ATM and Ethernet networks was a valuable experience.

... A lot was learned during this project. I liked how it used 2 different technologies (Ethernet and ATM) which helped me get a good feel for the two. This allowed me to contrast and compare the two ... I really liked how easy it was to port from Ethernet to ATM. Also the porting to Linux went pretty smoothly.

Overall, the students liked the comparison of two different technologies. The ATM socket interface developed by the Linux-ATM [3] group was critical to the success of this project. The students could easily modify their regular TCP socket programs to port to the ATM network.

6 Summary

This paper describes our efforts to teach advanced networking concepts such as wireless and ATM networking in undergraduate and graduate courses. A network instructional facility containing ATM and wireless equipment has been established at Washington State University and is being established at North Carolina A&T University. The course details and the experience obtained from teaching an undergraduate computer network course has been described.

Acknowledgments

The authors acknowledge the help provided by Indu Mahadevan, Abhishek Srivastava, Satish Damodaran and Nilesh Bhide – graduate students in the School of EECS – with the installation of the laboratory, especially Ms. Mahadevan's efforts.

References

[1] Fore Systems. http://www.fore.com.

[2] The Netperf Homepage. http://www.cup.hp.com/netperf/NetperfPage.html.

[3] ALMESBERGER, W. Linux ATM Homepage. http://lrcwww.epfl.ch/linux-atm, July 1998.

[4] COMER, D. *Internetworking with TCP/IP, Vol III: Client-Server Programming and Applications, Socket Edition*, 2 ed. Prentice-Hall, 1996.

[5] COMER, D. *Computer networks and Internets.* Prentice-Hall, 1997.

[6] INSTRUCTOR. CptS/EE 455: Class Webpage. http://www.eecs.wsu.edu/~krishna/cs455/index.html, May 1998.

[7] KESHAV, S. *An Engineering Approach to Computer Networking.* Addison Wesley, 1997.

[8] LUCENT TECHNOLOGIES. The age of wireless LANs has arrived. http://www.wavelan.com/, 1996.

[9] PAHLAVAN, K., AND LEVESQUE, A. H. Wireless data communications. *Proceedings of the IEEE 82*, 9 (Sept. 1994), 1398–1430.

[10] PRYCKER, M. D. *Asynchronous Transfer Mode: Solution for Broadband ISDN*, 3 ed. Prentice Hall, 1995.

[11] TANENBAUM, A. S. *Computer Networks*, 3 ed. Prentice Hall, Mar. 1996.